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Effects of Seating Configuration And Number of Type III Exits on Emergency Aircraft Evacuation

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16. Abstract

INTRODUCTION. An increase in the required pathway width from aircraft center aisles to Type III overwing exits is being weighed by the FAA. To augment the analysis, an examination of seat/exit configuration effects on simulated emergency egress was conducted in the CAMI Evacuation Research Facility. METHODS. Four subject groups traversed four different seat/exit configurations in a counter-balanced, repeated-measures design. Pathway width was modified by altering seat pitch. RESULTS. In single-exit trials the fastest times and highest flow-rates occurred with a 20" pathway between triple seats or a 10" pathway between double seats. Double exits produced 36% shorter egress times ($p<.007$), although flow-rates declined 11% and exit plug removal times increased 32%, compared to single exits. CONCLUSION. Efficient egress requires optimization of the space around the exit. Generally, wider pathways and fewer obstructions enhance this process; however; when available space exceeds individual passenger needs, conflicts may be produced which inhibit egress.

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EFFECTS OF SEATING CONFIGURATION AND NUMBER OF TYPE III EXITS ON EMERGENCY AIRCRAFT EVACUATION

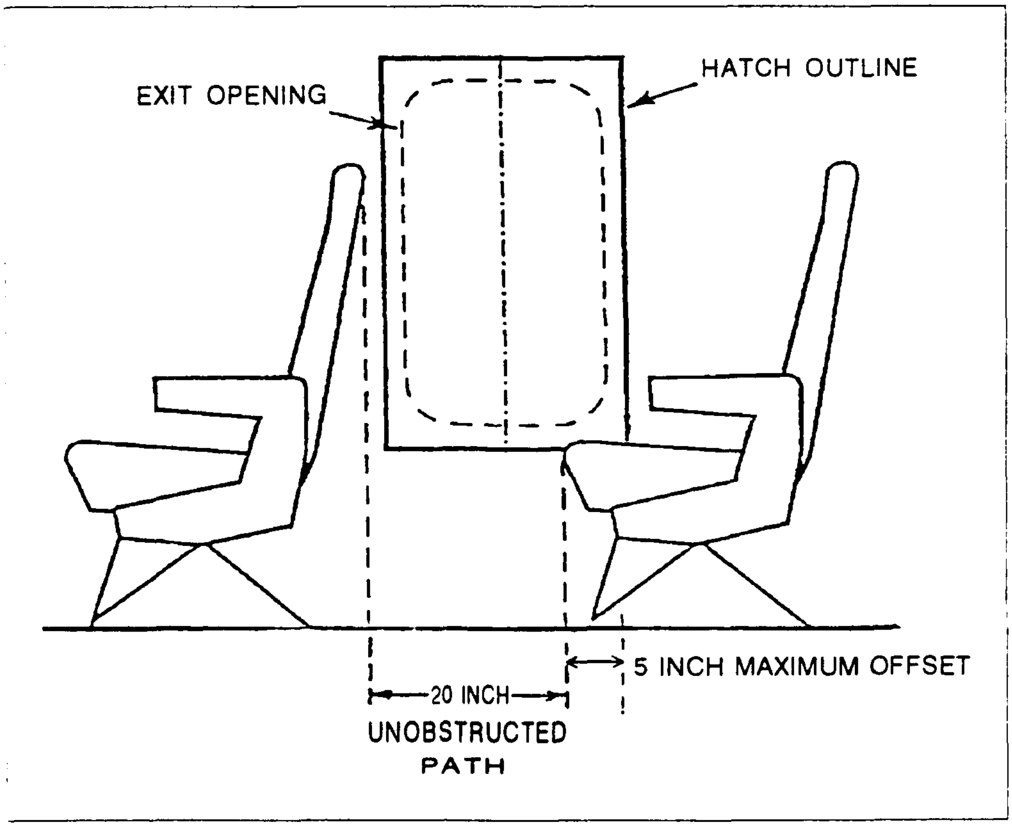
INTRODUCTION

The FAA Regulations Branch (ANM-114) of the Transport Airplane Directorate located in Renton, Washington, issued a Notice of Proposed Rulemaking (NPRM) on April 9, 1991, designed to require improved access to Type III overwing emergency aircraft exits (1). The basis for the proposed rule was derived from research conducted by the FAA Civil Aeromedical Institute (CAMI), as published in document DOT/FAA/AM-89/14, The Influence of Adjacent Seating Configurations on Egress Through a Type III Emergency Exit (2). Since the issuance of the NPRM, ANM-114 has found that additional information could be beneficial in implementing the proposed rule, and has requested that CAMI provide such additional information. To support this request, the Cabin Safety Research Section conducted a second study to examine the effects of seating and exit configurations on emergency egress. The following seat/exit configurations were tested:

SEAT/EXIT CONFIGURATIONS

A. An interior cabin arrangement that consisted of triple passenger seat assemblies located on both sides of the center aisle, with the seat assembly set aft of the Type III exit positioned so that the front edge of the seat cushion extended no farther than 5 inches forward of the aft edge of the exit opening. The seat assembly located forward of the Type III exit was positioned with the aft edge of its seatback located 5 inches in front of the forward edge of the exit opening. This combination of seat assembly locations provided a 20-inch-wide pathway from the center aisle to the exit opening. The seats forward and aft of the exit opening had the recline function locked out, and breakover was restricted to assure the declared pathway width from the center aisle to the exit opening. The remaining seat assemblies were positioned at a 32- to 34-inch pitch; the center aisle was 19 inches wide at the inboard armrests of the seat assemblies. See Figure 1.

FIGURE 1. CONFIGURATION "A"



B. The second interior arrangement was similar to that used in configuration "A." However, the seat assembly forward of the exit opening was moved aftward to place the aft edge of its seatback at the forward edge of the opening and the seat assembly aft of the exit opening was moved 5 inches farther forward to encroach upon the exit opening by 10 inches. This placement provided a 10 inch pathway completely adjacent to the opening of the Type III exit. The seatbacks on the seat assembly immediately forward of the exit opening were fixed in a broken-over position 15 degrees (forward) past plumb. See Figure 2.

C. This cabin interior arrangement was configured with a 10-inch pathway determined using the method in configuration "B," except that double seat assemblies were placed on the side of the center aisle proximal to the exit opening. Triple seat assemblies were placed on the side of the center aisle distal to the exit opening, creating an arrangement which resembled an airplane with 5-abreast seating (e.g., DC-9). The triple seat assemblies distal to the center aisle were installed to maintain a center aisle width of 19 inches as in configuration "A." See Figure 3.

D. This cabin interior arrangement utilized triple seat assemblies, as arranged in configuration A, and 2 Type III exits configured to provide a distance of 29 inches between their vertical center lines. However, 2 double seat assemblies replaced the triple seat assemblies adjacent to the exits; these double seat assemblies were positioned to simulate triple seat assemblies from which the outboard seat had been removed. This configuration provided 3 6-inch pathways: 1 fore, 1 aft, and 1 between the 2 double seat assemblies. See Figure 4.

NOTE: A center aisle width of 20-22 inches was originally requested by ANM-114; however, the 19-inch aisle width was chosen to facilitate the research protocol.

METHODS

The study was conducted in the CAMI Evacuation Research Facility (ERF) located in Oklahoma City. The research employed a within-groups experimental design, in which 4 groups of 39 human subjects were required to exit the ERF, using all of the seating/exit configurations described above. A counterbalanced experimental design was used to compensate for the effects of evacuation experience and other possible confounding variables, such as motivation and fatigue (Table 1).

Test subjects ranged in age from 19 to 61 years, with no more than 60% of either gender in each group.

FIGURE 2. CONFIGURATION "B"

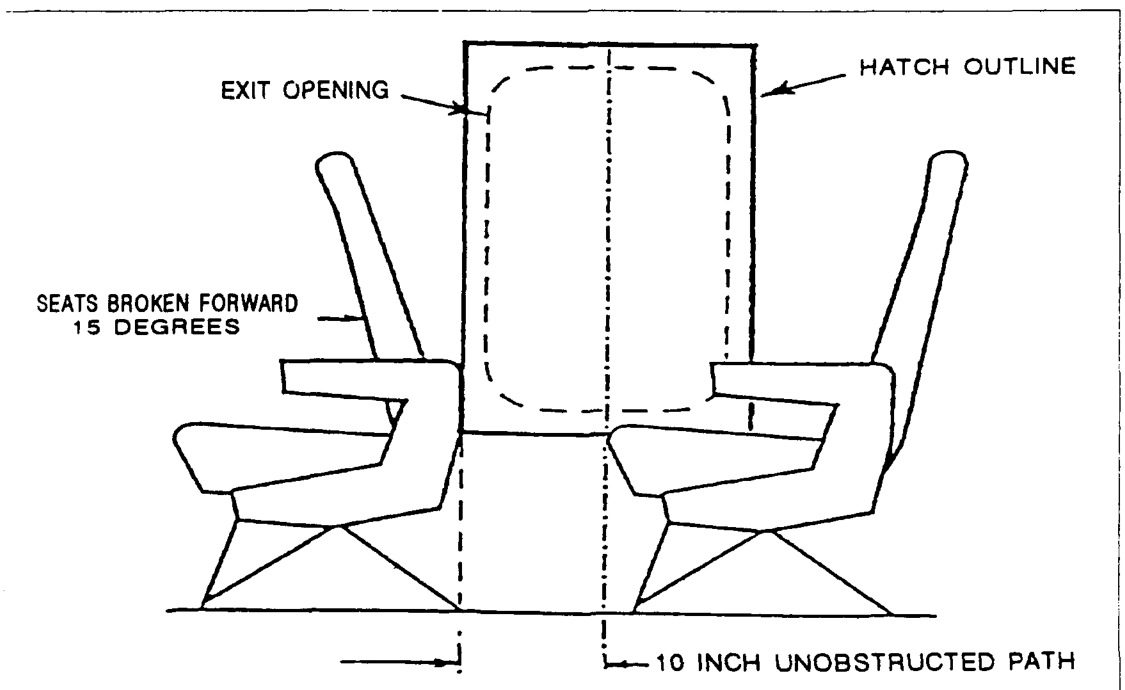


FIGURE 3. CONFIGURATION "C"

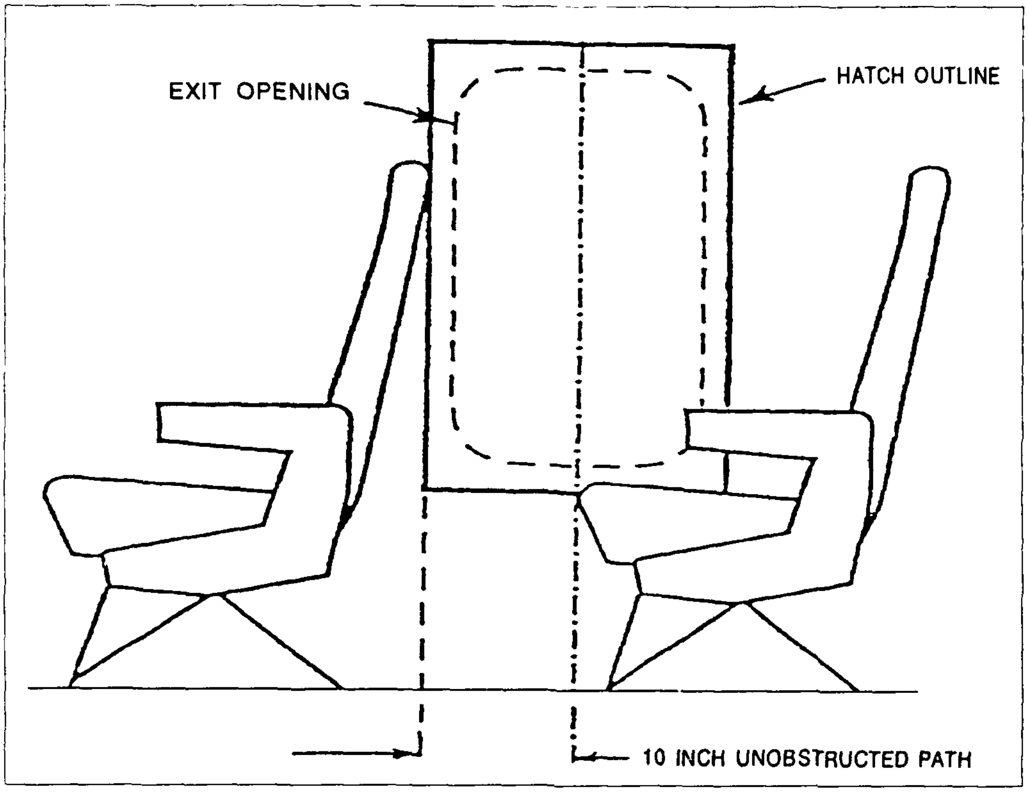


FIGURE 4. CONFIGURATION "D"

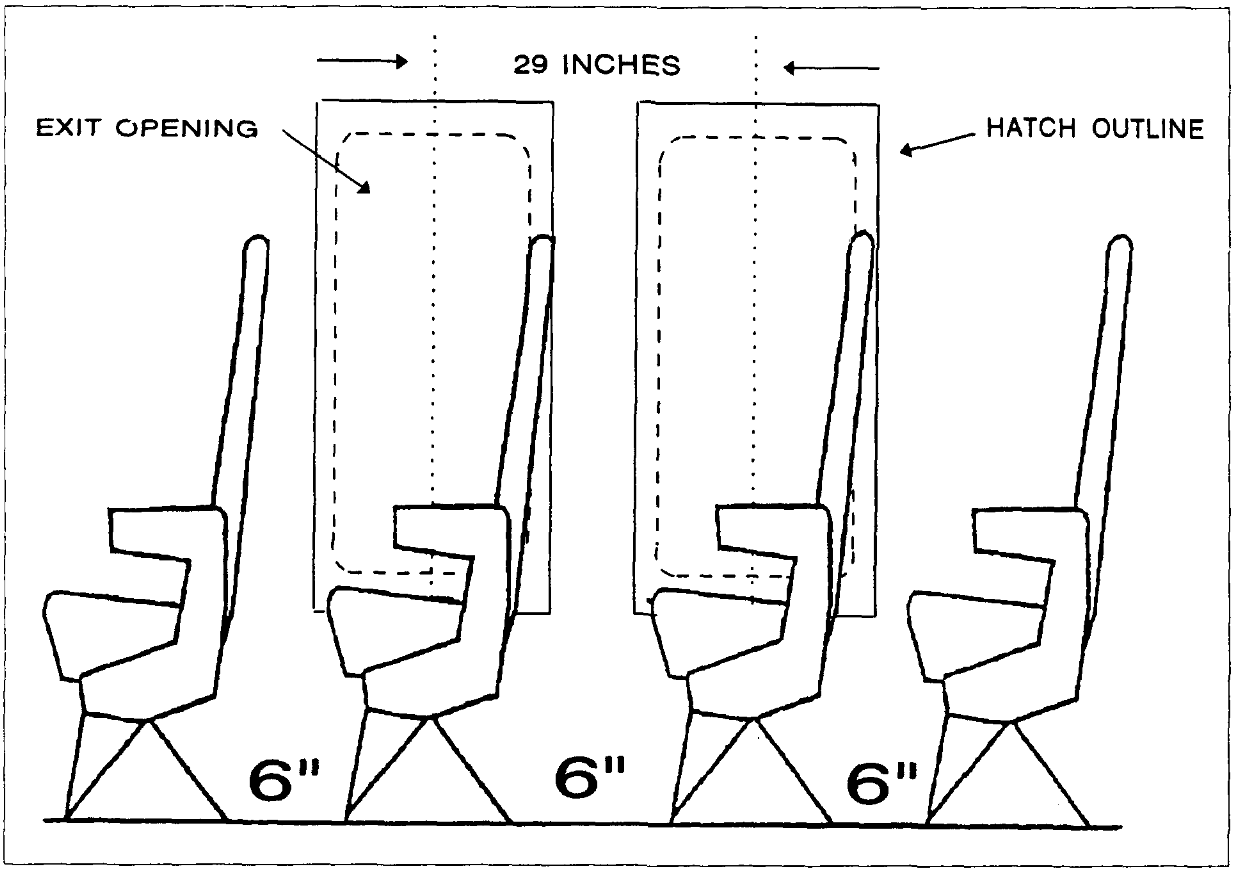


TABLE 1. COUNTERBALANCED RESEARCH DESIGN

DAY	CONFIGURATION			
1	A	B	C	D
2	D	C	B	A
3	B	D	A	C
4	C	A	D	B

Subjects reported to CAMI at 8:00 AM on test days; they were briefed, given medical examinations, and required to provide informed consent to participate. After this preliminary activity, they were escorted to the ERF, where they were given a safety briefing and instructions about the research task. (Examples of the briefing materials are provided in Appendix I.) After the briefing, the start of the first evacuation was signaled by the sounding of a loud bell. After the initial evacuation, the subjects were escorted back into the building while the ERF seating/exit configuration was being changed. Upon completion of the change in seating/exit configuration, the subjects were escorted back to the ERF to begin another briefing/evacuation sequence. After the fourth and final evacuation exercise, the subjects completed the necessary paperwork for payment. All test runs were recorded by 4 video cameras; 2 cameras were placed inside the ERF and 2 cameras were placed outside the ERF. A time-code marker was imposed on each videotape for scoring purposes.

RESULTS

The results of this study are presented as the respective times required to accomplish the different evacuations. These egress times were derived from manual observation of the videotapes by 2 trained observers who recorded the time-codes imprinted upon the relevant frames. A resolution of 30 frames per second (33.3 msec per frame) was achieved; discrepancies between observers were refereed by a third observer. Note that in all the Tables below, the times have been reorganized by seating/exit configuration across evacuation trials, not experimental days. This reorganization was accomplished to control for the likely "repeated measures" effects (such as evacuation experience) and allow for a better comparison of each seating/exit configuration.

The total time for each group to evacuate the ERF in each of the seating/exit configurations is shown in Table 2. These times include the time required to remove the exit hatch plug and the cumulative time for all 39 subjects to exit the facility completely. The subjects who were seated at the exits chose these seats themselves; no attempt was made by the research team to choose an obviously able subject to sit in that location. The only attempt to assure that the subject seated at the exit opening was capable of opening the hatch was to ask him/her after being seated if opening the exit hatch would be a problem. If so, he/she was then allowed to move to another seat, and a second volunteer was sought to sit at the exit. Only once did this prove to be a problem, and the subject exchanged seats with the subject sitting next to her. Similarly, the research team did not instruct the subjects on how to operate the exit hatch, except for instructing them to read the briefing card in the seatback. Thus, while these total evacuation times are necessary to provide a complete view of the evacuation processes, their usefulness in determining the effectiveness of any particular seating/exit configuration is confounded by the strategies and abilities of the subjects who were responsible for opening and removing the exit plug.

To provide a more useful view of the time required for exit hatch opening, as well as flow rates, the total evacuation times were partitioned into 2 phases: 1) the time required to open and remove the hatch plug and 2) the time required for the 3rd through the 37th subject to egress. The time required to open and remove the exit hatch plug was measured from the sounding of the bell that began the egress trial until the subject who opened the hatch first entered the exit opening. The time required for the first subject to enter the opening was included in this phase because of the likelihood that this subject would be out-of-position relative to the normal approach to the door, and that any repositioning time necessary to get oriented to the exit would affect the results. Similarly, the second subject out of the ERF was excluded from both analyses to provide a buffer between exit opening/removal and steady egress, to obtain as pure a measure of flow-rate as possible. The last 2 subjects to get out were also excluded to control for the lack of a "push" from subjects behind them. The times for exit hatch opening and removal are shown in Table 3; note that times are given for both "D" configuration exits.

TABLE 2. TOTAL TIME IN SECONDS FOR ALL SUBJECTS TO EGRESS

	CONFIGURATION			
TRIAL	A	B	C	D
1	91.67	74.03	81.86	72.36
2	74.90	82.50	87.37	39.00
3	64.20	89.83	80.93	46.60
4	77.16	82.54	62.36	43.90
MEAN	76.98	82.23	78.13	50.47
STD.DEV.	9.79	5.59	9.43	12.93

TABLE 3. TIME IN SECONDS TO REMOVE THE EXIT HATCH COVER

	CONFIGURATION				
TRIAL	A	B	C	Da	Db
1	6.83	5.37	6.43	13.10	8.57
2	4.47	8.86	4.14	5.53	6.30
3	5.13	3.70	7.23	6.67	5.60
4	4.16	4.87	4.03	5.87	5.80
MEAN	5.15	5.70	5.46	7.79	6.57
STD.DEV.	1.03	1.92	1.40	3.09	1.18

Da = Forward exit; Db = Aftward exit

TABLE 4. MEAN TIME IN SECONDS FOR EACH SUBJECT TO EGRESS

	CONFIGURATION				
TRIAL	A	B	C	Da	Db
1	2.21	1.78	1.92	3.10	2.91
2	1.80	1.96	2.13	1.53	1.46
3	1.53	2.14	1.92	2.00	1.93
4	1.86	2.04	1.48	2.22	1.75
MEAN	1.85	1.98	1.86	2.21	2.01
STD.DEV.	.72	.67	.68	1.12	1.20

Da = Forward exit; Db = Aftward exit

The average times required for each subject to egress completely are shown in Table 4. These times reflect the flow-rates through each seating/exit configuration, and have been derived by subtracting the time at which the last body part of any preceding subject emerged from the ERF from the time at which the last body part of the next subject emerged from the ERF. This method was chosen to assure consideration of flow-rate through the seat/exit configuration, not merely flow-rate through the Type III exit opening, as would have been the case by measuring the time from the point at which a subject's first body part entered the Type III exit opening until his/her last body part emerged from the exit opening.

DISCUSSION

The results of this study support and extend the earlier findings by Rasmussen and Chittum (2). The "A" seating/exit configuration with the 20-inch pathway leading from the center aisle to the single Type III exit provided the most efficient egress of any of the single Type III seating/exit configurations studied. In all 3 categories - total egress time, exit hatch plug removal time, and individual subject egress time (flow-rate) - the "A" configuration provided the fastest performance. By contrast the "B" configuration, in which the pathway width was reduced to 10 inches, provided the longest egress times, even though the seats forward of the exit were broken-over forward 15 degrees past plumb. The "C" configuration, in which 5-abreast seating with the 10-inch pathway was used, provided egress times intermediate to the "A" & "B" configurations; the egress times for "C" much more closely resembled those for the "A" configuration than for "B." The differences in exit hatch plug removal times among the 3 single exit configurations were rather small, and contributed little to the seating configuration effects shown on total egress time.

This combination of results indicates that, of the total egress time required to exit through a single Type III exit, the amount of time needed for a passenger to move from the center aisle through the pathway and out the exit is highly dependent on the ergonomic restrictions encountered around the exit hatch opening. This effect is highlighted in the shorter egress times shown when either "A" (increasing the pathway width) or "C" (decreasing the restricted distance to be traversed) configurations were tested, relative to the most ergonomically restrictive "B" configuration.

Additional reductions in egress time should be expected when combining both the "A" and "C" approaches to reduce ergonomic restrictions further. However, this enhancement in egress would cease to be augmented when arriving at the minimum time required to merely "step-through" the Type III exit hatch opening. In addition, Muir et al (3) have shown in a study of competitive egress that, when the available ergonomic workspace around the exit hatch opening allows competition between passengers for that space, blockages are produced at the exit hatch opening which reduce egress rate from optimum. They found that egress through a single Type III exit could be augmented by increasing the width of the pathway to a maximum of 25 inches, after which increasing the pathway width caused the flow rate to decline. They also found that removing the outboard seat produced a comparable effect, except when an orderly, noncompetitive, evacuation was in progress.

The egress times obtained using the "D" configuration generally support these conclusions. Recall that in this configuration the 3 6-inch pathways lead to 2 exit openings. Except for total egress time, where the dual exits allowed for a greater number of subjects to exit the ERF in parallel, a general increase in the time required to accomplish evacuation activities was noted. The increase in exit hatch plug removal time indicated that because the outboard seats had been removed in this configuration, the subjects had to lean far over or get out of their seats to remove the exit hatch plugs. This requirement increased the exit hatch plug removal times by an average of 1.5 to 2 seconds (30% to 40%) over the single exit hatch plug removal times. The individual egress times (flow-rate) also reflected an increase in evacuation time caused by restricted ergonomic activity. This effect primarily resulted from the reduction in pathway width, although several of the subjects displayed some degree of hesitancy in the area immediately near to the exit hatch opening. However, this latter effect seemed to depend less on competition for ergonomic workspace than on uncertainty about who should enter the workspace available, i.e., "not knowing who should go next." This problem was highlighted by 1 instance in which a single subject remained stationary in the rear-most pathway during the evacuation trial and motioned subjects coming from the rear to use only the middle pathway. This polite gesture eliminated the uncertainty problem.

These findings suggest that, in opposition to the suggestions for enhancing egress in the single Type III exit configuration, expanding the width of the 3 pathways to allow easier access to the dual exits (and more opportunity for confusion at the exit openings) might produce a net loss in egress efficacy. Instead, a net gain in egress efficacy should be possible by replacing the double seat assemblies with triple seat assemblies and arranging them so that only 1 appropriately configured pathway leads to each of the dual exits, effectively producing 2 independent single Type III exits. This approach could be difficult to implement in aircraft with dual Type III exits distanced at 29- inch vertical centerlines; however, on aircraft with a greater distance between the dual Type III exit hatch openings, this design would appear to be most desirable.

Attention to such details should enhance the ability of passengers to accomplish emergency egress with added speed and safety, thereby promoting increased survivability in aircraft accidents.

REFERENCES

1. Department of Transportation, Federal Aviation Administration, *Increased Access to Type III Exits; Notice of Proposed Rule Making,* NPRM 91-11, Docket No. 26530, Federal Register, Vol. 56, No. 68, 9 Apr 1991.

2. Rasmussen PG, Chittum CB, *The Influence of Adjacent Seating Configurations on Egress Through a Type III Emergency Exit.* Washington, DC; Department of Transportation/Federal Aviation Administration: 1989; Publication No. DOT/FAA/AM-89/14. Available from the National Technical Information Service, Springfield, VA 22161. Order No. ADA218393.

3. Muir H, Marrison C, Evans A, *Aircraft Evacuations: the Effect of Passenger Motivation and Cabin Configuration Adjacent to the Exit,* CAA Paper 89019, London, November 1989.

APPENDIX A

INITIAL SUBJECT BRIEFING

Welcome to the Protection and Survival Laboratory of the Civil Aeromedical Institute. The research we are conducting today promotes improved aircraft safety. The only way we can complete this type of research is through the help of people like yourselves. Your participation in the project is greatly appreciated and you may take satisfaction in knowing that your actions today could possibly result in saving lives in the future.

The study we are conducting is designed to determine the effects of different aircraft seating arrangements on emergency evacuations from aircraft. Today we are interested in four such aircraft seating arrangements, and to participate in the study you will be required to evacuate the test facility four different times. There will be delays between each evacuation to allow the research team time to prepare the test facility for the next evacuation, and you will be escorted back here to this lobby during these delays. Because the changes to the test facility take different amounts of time that vary from about 10 minutes or so to nearly an hour, we cannot be exactly sure when the next evacuation will occur and we ask that you **PLEASE REMAIN WITH THE GROUP AT ALL TIMES.** Just before we begin the evacuations, and during the longest delay period, we will allow you time for personal needs. The evacuations will require you sit in an aircraft seat, move quickly from that seat down the aisle to the exit opening, and climb through an exit opening 38 inches high by 20 inches wide. This opening is 19 inches above the floor inside the test facility and 27 inches above the ground outside the test facility. All this activity will, of course, require you to exercise and to step up and down to get out of the test facility. In order to participate in the test you must not have a disability or medical condition that might impair your ability to see and hear our instructions, move rapidly and effectively, or endanger you in any way. **To assist us in helping you to determine whether any condition you possess might affect your ability to perform safely, we ask that you complete the medical and physical history form we have provided.**

Prior to completing that form, however, you must complete the consent form on the top of your packets. This form indicates your understanding about our research, your consent to provide us the required information and to participate in this research study. **ANY QUESTIONS ?**

If you agree to participate in the test you may now start completing the informed consent form. After the completion of all tests, return to this room and fill out your pay voucher. If you do not fill out the voucher, you may have difficulty in obtaining your pay.

SAFETY BRIEFING

Good morning ladies and gentlemen. I am ____________________ and I will be your safety officer during today's tests. The research we are conducting today is very important for aviation safety, but we are just as concerned with your personal safety. By their nature, emergency evacuations are potentially unsafe. Ninety percent of all severe injuries which occur in survivable aircraft accidents happen during the evacuation stage of the accident. Although this test is only a simulation, the hazards you could encounter are representative of those you could experience in an actual emergency evacuation, and while we have taken every foreseeable precaution to insure your personal safety, occasionally the unexpected happens. Thus, if an actual emergency condition arises during the test, a member of the research team will stop the evacuation by shouting **STOP until all** activity ceases. Should the test be stopped in this manner, please get as quiet as possible and remain stationary until you are given further instructions. **ANY QUESTIONS ?**

TASK BRIEFING

Please fasten your seat belts securely, by inserting the metal end into the buckle, like this **(demonstrate)**. Use the buckle strap to adjust the length, like this **(demonstrate)**. At the start of the test you will release the buckle by lifting up on the top plate, like this **(demonstrate)**. Now make sure your seat buckle is securely fastened.

Those of you who are sitting at the exit rows **(point)** will find a passenger briefing card **(show one)** in the seatback in front of you. This card shows how to remove the exit hatch door. Please familiarize yourself with this information **(allow time to study the card and ask those subjects if they are ready; proceed when they indicate they are ready)**.

The test will begin shortly when you hear this bell **(sound the bell for a couple of seconds)**. When you **first** hear the bell, release your seat belt and exit through the Type III exit opening as quickly as possible **(point out the exit opening(s))**. Once you are outside, move away from the test facility as quickly as possible. Follow the roped-off corridor to the staging area, where a research team member is waiting to assist you back into the building. Remember, **please stay with the group after leaving this facility. ANY QUESTIONS ?**

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